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A basin-wide approach to dredged material management in New York / New Jersey Harbor

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Abstract

In the last decade, an area of increasing estuarine research in the New York/New Jersey Harbor has been the identification of toxic contaminant sources, mapping of contaminant levels in water and sediments, and assessment of contaminant accumulation in biota. The accumulation of anthropogenic contamination in the harbor's sediments has occurred for centuries, primarily from land-based municipal and industrial sources. Contaminants from land-based sources introduced into surface waters rapidly become scavenged by suspended particles that then tend to settle to the bottom, primarily in deep areas, such as berths and navigation channels. Several million cubic meters of sediments must be dredged annually to clear navigation channels. In the past, the dredged material was disposed in a designated ocean site. However, in1992, new testing procedures were implemented, and much of the harbor's dredged material was determined to be unsuitable for ocean placement. It is ironic that these restrictions came at a time when the quality of harbor sediments is improving, largely because of pollution controls implemented as a result of the Clean Water Act and other environmental measures put in place by government and industry. For example, the harbor-wide concentration of mercury has decreased to 0.7–0.8 ppm, a level that is approaching the pre-industrial background level. Nevertheless, in certain areas of the harbor, there remain sufficiently high concentrations of contaminants to merit concern and to create serious problems for sponsors of dredging projects. Development of a basin-wide sediment management strategy is necessary to guide port decision-makers in their efforts to clean-up contaminant sources, to dredge regional waterways, and to ameliorate the contaminated sediment disposal problem. The backbone of this strategy is the integration of the data from an ongoing field monitoring and modeling program with a parallel investigation of watershed and airshed sources and sinks using industrial ecology methodology.

Keywords: Contaminated sediments; Port management; Beneficial uses; Pollution prevention; Industrial ecology

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1. Introduction

The New York/New Jersey Harbor is located in a complex aquatic network created by three New York islands (Staten Island, Long Island and Manhattan) and the New Jersey shore; it encompasses numerous channels and several interconnected sub-bays (Fig. 1). It receives freshwater discharges from the Hudson, Raritan, Passaic and Hackensack rivers, which contribute to its complex hydrodynamics and heavy sediment load. The Atlantic Ocean enters through Lower New York Bay, which is connected to Raritan Bay on the west and Upper New York Bay to the north. To the west of Upper Bay, connected through the Kill Van Kull Channel, is Newark Bay where the Passaic and Hackensack rivers converge. The Hudson–Raritan watershed has an area of about 42,000 km^2, and the airshed influencing the area is about 246,000 km^2 [1]. The harbor covers an area of about 3885 km^2 with over 1240 km of waterfront [2].

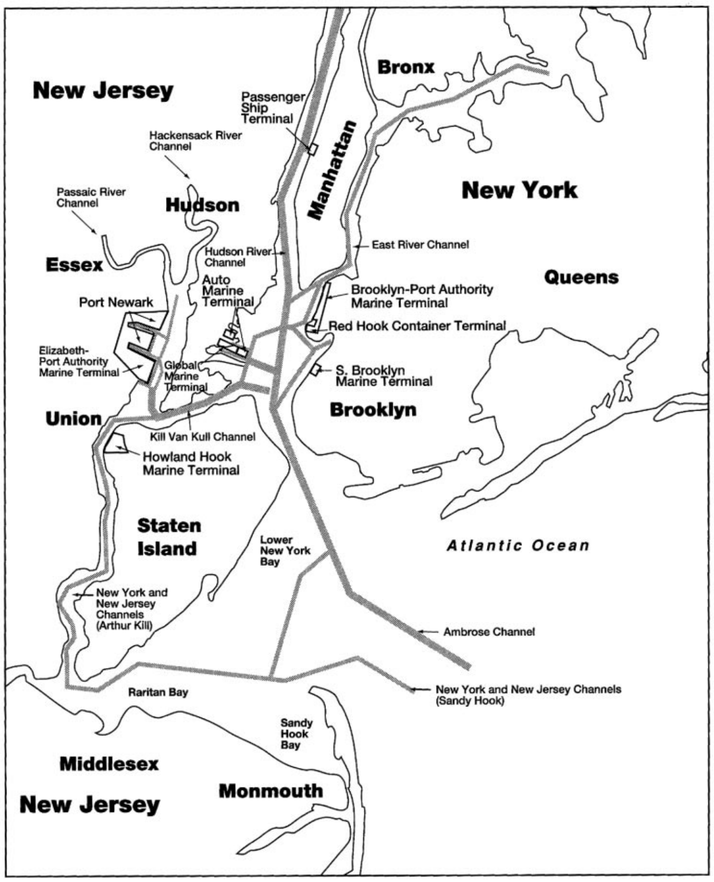

Fig. 1. Port of New York and New Jersey.

The population of the metropolitan region has increased steadily to over 21 million residents. The continuous population and concurrent economic expansions have directly impacted the Hudson–Raritan watershed [3]. For nearly a century, the region served the entire nation as the center for major manufacturing and industrial operations. These activities caused degradation to the major rivers and estuarine environment. Besides being filled to expand waterfront access, the harbor's waterways were impacted by massive discharges of municipal and industrial wastes containing heavy metals, pesticides, oils and greases, and other chemicals. Some controls to stem the aquatic pollution were begun in the 17th century. Collection of wastewater in New York City was started in 1696, but it was not until 1886 that the first wastewater treatment plant was constructed [4]. Uncontrolled discharges continued, and fisheries became contaminated and declined [5]. By the mid-1960s, the harbor's environmental degradation and concurrent human health impacts, as well as similar problems in other parts of the nation demanded legislation, regulations, and enforcement activities. The National Environmental Policy Act was the first major national legislation to address these concerns. During the 1970s, several other national, state, and local laws were passed to control air, water, and land pollution. By 1972, when the Federal Water Pollution Control Act ("Clean Water Act") was passed, the Hudson–Raritan estuary was receiving nearly 2 million m^3 of raw sewage per day [4]. At that time, regulatory efforts were focused on construction of municipal facilities, and most industrial effluents were discharged untreated.

Since the 1970s, pressure from the courts, the US Environmental Protection Agency (USEPA), and various state and local regulatory agencies has resulted in public and private investments in municipal and industrial water pollution controls and significant improvements in water quality. O'Shea and Brosnan [6] reported that the water in the Hudson–Raritan complex was cleaner than it had been in 6 decades. There is no longer floating waste or smells of sewage [4]. The public is rediscovering the estuary and claiming it for recreation and aesthetic enjoyment. The sediment contaminant levels also declined, as the largest generators of wastes were regulated [7]. However, there is a large reservoir of contaminated sediment in the harbor, and the riverine flows annually discharge new contaminated sediments. Fish remain too contaminated to eat regularly [8], and the problem of disposing contaminated dredged sediments from navigation channels has threatened to close the harbor [9].

2. Dredging operations

The Port of New York and New Jersey has been a working harbor for over 300 years. It is an important international gateway for the United States' commercial trade and military transport with Europe, Latin America, the mid-East and other locations. It is the largest automobile and petroleum port and the third largest container port in the US. Each year, over 5000 ocean going vessels move cargo into and out of the New York Harbor. Although modern tanker and container vessels require navigation channels with depths from 12.5 to 15 m [10], New York Harbor is naturally shallow with an average depth of about 6 m. Every year, with winter and spring freshwater inflows, approximately 1–2 million m^3 of sediment enter the harbor from the Hudson, Passaic, Hackensack and Raritan rivers. Also, about 1 million m^3 of ocean sand enters the harbor in the tidal flow through the Ambrose Channel in Lower New York Bay. Some of the sediment entering the system is removed naturally as the riverine and tidal flows carry it into the coastal ocean. However, most of this sediment must be dredged. Historically, about 6.5 million m^3 have been dredged annually to maintain and to improve navigable depths at existing channels and berthing facilities [11,12].

Since 1800s, the New York Bight Apex and surrounding area have been used for disposal of dredged materials and a variety of wastes including garbage, sewage sludge and industrial waste [13]. Since 1973, dredged sediments have been ocean-discharged almost exclusively at the mud dump site located approximately 10 km off of the New Jersey Coast. However, in 1992, the USEPA and the US Army Corps of Engineers (USACE) implemented new sediment testing procedures and most of the harbor's dredged material was determined to be too contaminated for ocean disposal. The limited capacity of the ocean disposal site and public concerns regarding fish contamination led the federal government to close the site in September 1997 and to open a new site, designated the historic area remediation site (HARS). This 54 km^2 site encompasses the former mud dump site (7.6 km^2) and some other waste disposal sites that were used earlier in the New York Bight Apex [13]. HARS is limited only to the cleanest material; sediments deemed suitable are used to remediate the site by capping the contaminated sediment [13].

It is ironic that these new regulatory restrictions came at a time when it was becoming evident that the quality of harbor sediments was improving dramatically, largely because of pollution controls implemented under the Clean Water Act, the Clean Air Act, and other environmental regulatory measures. In order to evaluate the level of contamination, it is instructive to compare the prevailing "contaminant" concentrations to the concentrations that existed prior to emissions of anthropogenic origin. Table 1 summarizes background metal concentrations in fine-grained sediments in very deep cores collected in Hudson river and harbor area reported by a number of investigators [14–16]. For example, the background level of mercury has been estimated at less than 0.3 ppm. In comparison, the mean concentration of mercury harbor-wide concentration of mercury [17], for samples taken in 1991 at 38 different locations in the harbor, showed an average mercury concentration of 2.29 ppm, i.e. an order of magnitude higher than the background value. On the other hand, a 1993–1994 sampling of 168 sites by Adams et al. [18] showed (Table 2) that the mean

Table 1
Pre-industrial metal concentrations in Hudson drainage basin[a]

	[14]	[15]	[16]	Average concentration in shale [15]
Cadmium		0.5	0.11	0.3
Chromium		60		90
Copper	20	25	14	45
Lead	25	20	15	
Mercury		0.3		0.4
Nickel		35		68
Silver			0.25	
Zinc	80	80	81	95

[a] Concentration in ppm.

Table 2
Area-weighted mean sediment contaminant concentrations[a]

	ERL concentration	ERM concentration	Harbor-wide (+90% CL)	Upper harbor	Lower harbor	Newark Bay
Trace elements (ppm)						
Antimony	2	25	1.49 + 0.48	1.11	1.24	6.27
Arsenic	8.2	70	10.33 + 2.05	9.04	10.01	25.51
Cadmium	1.2	9.6	0.79 + 0.13	0.93	0.54	2.52
Chromium	81	370	78.09 + 10.11	92.44	71.48	137.31
Copper	34	270	72.53 + 17.4	110.12	47.29	226.69
Lead	46.7	218	78.84 + 12.83	96.55	63.78	193.92
Mercury	0.15	0.71	0.74 + 0.14	0.80	0.61	2.59
Nickel	20.9	51.6	24.07 + 2.9	30.92	20.08	50.81
Silver	1	3.7	1.59 + 0.30	2.28	1.29	2.98
Zinc	150	410	170.06 + 25.56	166.68	162.56	308.04
Organics (ppb)						
Total PCBs	22.7	180	224.35 + 42.25	428.74	120.46	755.62
Total DDT	1.58	46.1	31.59 + 16.64	19.84	10.28	320.31
Acenaphthene	16	500	82.78 + 65.43	294.62	17.81	92.82
Acenaphthylene	44	640	122.93 + 41.89	381.64	40.84	202.461
Anthracene	85.3	1100	365.05 + 220.76	1335.14	63.54	511.49
Benzo(a)anthracene	261	1600	486.83 + 129.35	1525.6	141.74	905.11
Benzo(a)pyrene	430	1600	303.05 + 83.12	889.96	113.25	516.92
Chrysene	384	2800	544.76 + 145.85	1653.2	161.69	1076.9
Dibena(a,h)anthracene	63.4	260	79.42 + 31.10	247.84	26.66	146.12
Fluoranthene	600	5100	743.25 + 278.61	2308.0	201.34	1280.0
Fluorene	19	540	176.41 + 182.11	693.43	28.20	107.72
2-Methylnapthalene	70	670	89.91 + 42.02	253.21	33.04	114.36
Napthalene	160	2100	163.96 + 100.34	528.57	48.90	217.87
Phenanthrene	240	1500	628.06 + 520.48	2368.6	116.85	417.30
Pyrene	665	2600	767.6 + 269.73	2491.0	202.19	1144.7
Total PAHs	4022	44792	7177.4 + 2607.9	22141	2179.2	11471
Tributyltin	–	–	4.17 + 0.52	4.11	3.94	5.39

[a] Tables 4–1 and E-1 of [18].

concentration of mercury in sediments had decreased to 0.73 ppm, i.e. only 2.5 times the pre-anthropogenic background.

Therefore, on the basis of the mercury data over the entire harbor, a tremendous amount of progress in pollution reduction has been made. However, mercury analysis of sediments collected by the Port Authority of New York and New Jersey (Table 3) in several of the harbor's terminals show mercury levels one and even two orders of magnitude higher than the Adams et al. [18] values. It is evident that in certain areas, there are enough residual contaminants remaining in harbor sediments to merit concern and to create significant problems for sponsors of dredging projects looking for disposal sites. If the material is too contaminated for the ocean, some say, then it is unsafe to place it in "our backyards". The result of these concerns about contaminated sediments presents a serious challenge to the managers of the port as they try to dredge for maintenance and channel deepening purposes.

Table 3
Mercury levels in selected ports of New York/New Jersey terminal sediments[a]

Facility	Year	Low range	High range
Howland Hook	2000	0.32	18.1
Howland Hook	1997	4.5	9.1
Brooklyn Piers	1997	1.1	5.4
Port Newark Reach A	1995	12.9	244
Port Newark Reach A	1990	3.2	876
Port Newark/Elizabeth Reaches B, C, D	1996	2.7	5.5
Port Newark/Elizabeth Reaches B, C, D	1990	1.5	9.7
Port Jersey Outer Channel	1998	0.2	3.4
Port Jersey Inner Channel	1997	10.6	22.1

[a] Concentration in ppm.

Table 4
Port of New York/New Jersey annual average volumes dredged and placement locations[a]

Disposal site	1970–1991	1992–1997	1998–1999
Ocean suitable at mud dump/HARS	6500000	2000000	637650
Ocean suitable with capping	–	53250	–
Unsuitable for ocean placement	Less than 100000	46700	810000

[a] New work and maintenance in millions of cubic meters.

In recent years, the Corps of Engineers has been assessing several potential options for handling dredged sediments [11]. The list has included the creation of contaminant islands, sub-aqueous pits, upstate land disposal and so forth. Most of these traditional disposal options have not been successfully implemented, primarily because of public opposition. An exception was the construction of a sub-aqueous pit that was excavated in Newark Bay in late-1996 [19]. The pit can contain and isolate approximately 1.2 million m^3 of dredged material that is deemed unsuitable for placement at the HARS. Some new "beneficial use" sites have also been developed for dredged material that is not suitable for HARS disposal including capping of landfill sites and brownfield remediation projects. However, using these sites is significantly more expensive than disposal at the former ocean site. The average cost to dispose a cubic meter of dredged material has risen from US$ 4 in 1992 to over US$ 40 in 2000. As disposal has become more difficult and expensive, dredging volumes in the harbor complex have declined (Table 4). In 1996, the total volume dredged had decreased to about 600,000 m^3.

3. Fisheries

Port managers and other maritime stakeholders are not the only victims of sediment contamination. The harbor area supports an enormous wealth of fish and shellfish ecosystems [5]. In 1990, the total commercial fisheries catch for the Hudson–Raritan estuary was approximately 1.5 thousand metric tonnes; recreational fish caught along the mid-Atlantic region offshore and in the estuary amounted to 82 million fish [20]. Unfortunately, New York and New Jersey have had to issue health advisories restricting consumption of many of the fish and shellfish caught in the estuary [8]. At a time when the population of striped bass in the Hudson river is once again thriving due to strict fishery management measures, commercial fishing of striped bass remains banned in this river and in Western Long Island Sound because of PCB contamination. The economic losses attributable to the closure of this fishery are considerable [5]. Other fish, including bluefish and blue claw crabs, are also contaminated with PCBs/dioxins and cannot be consumed.

Two studies, one mapping contaminated sediments [18] and the other monitoring levels of contamination in fish tissue [21,22], show that fish and other organisms in the harbor are bioaccumulating the same pollutants that make sediments unsuitable for disposal at HARS. Contaminated fish live in the areas where sediments are contaminated. The chemicals in contaminated fish and sediments are the same: PCBs, dioxins, and various heavy metals [20]. Furthermore, there is speculation that pollution and habitat destruction are reducing stock replenishing in the Northeast [23].

The field data give a general description of distribution and concentration of surfacial sediment contaminants in several sub-basins [18]. Table 2 shows the "effects range — low" (ERL), "effects range — median" (ERM), and area-weighted mean sediment concentrations for various inorganic elements and organic materials. ERL is the concentration at which adverse biological effects begin to be seen, and ERM is the level associated with adverse effect [24]. The Adams et al. [18] data suggest that marine organisms are suffering adverse effects from mercury (0.74 ppm) in the harbor. However, a toxicity study [17] indicated that at levels less than 1 ppm of mercury, the survival rate of amphipod organisms (one of the toxicity tests used) was near 100%. Clearly, additional data are needed to adequately understand the relationship of contaminant levels and harbor ecosystem health.

4. Sediment and contaminant management

In their dredging plan, the Corps of Engineers [12,25] have suggested that a 5% per year reduction in contaminant levels would cut the amount of contaminated material in dredged channels by about 40% over the next 25 years. The harbor community favorably received the Corps proposal for a contaminant reduction strategy. Researchers at Manhattan College [26] used a mathematical model to predict when dredged materials and fisheries will become clean under various contaminant reduction scenarios. Their results suggest that if pollution sources were reduced, then sediments and fish contaminant concentrations would decline proportionally to the degree of reduction; savings in disposal costs would be substantial because expensive control measures and disposal technologies, including chemical or other treatment, would no longer be necessary. Unfortunately, many contaminant sources, such as combined sewer overflows and non-point sources discharges, remain.

One systematic approach to dealing with the issue of contaminant reduction is to formulate a comprehensive basin-wide strategy for managing contaminants and sediments within the Hudson–Raritan watershed and the port. The geographic boundaries of the Hudson–Raritan watershed, such as mountain chains, limit the hydrologic inputs into the drainage basin. The major external source of contaminants into the hydrologic basin is the regional airshed (including atmospheric deposition and rainfall). All internal sources are either released upstream and flow into the harbor or are released directly into the harbor. Management of the entire drainage basin provides the means to substantially control the water and sediment quality at the downstream end, by controlling inputs along the hydraulic gradient and into the harbor. In short, the strategy should promote a basin-wide trackdown and clean-up program to curtail sediment and fisheries contamination.

A comprehensive sediment strategy must also include the promotion of pollution prevention measures and the development of beneficial uses of dredged sediments. Pollution prevention is the most effective method of eliminating diffusive environmental contamination. The States of New York and New Jersey have charged [4,27] their regulatory agencies with the aggressive reduction of municipal and industrial discharges of chemicals of concern, and the minimization of toxic chemical releases that result from combined sewer overflows and stormwater discharges. Moreover, both states have committed to the implementation of non-regulatory pollution prevention strategies, including the encouragement of municipal and industrial facilities to go beyond regulatory requirements and to commit to the voluntary reduction of chemical releases.

The second important theme under a comprehensive management strategy is to view sediment as a potentially useful resource. Much work has already been done to identify beneficial uses for dredged material, including construction, recreation and habitat uses [28]; but more work is needed to identify options particularly for contaminated dredged materials. There is also a need for clean-up processes to remediate localized in situ sediment areas that have very high levels of contamination. Gradual erosion from such areas contributes to the contamination of sediment shoals that naturally form in dredged channels and berths, making disposal of dredged material more difficult. Ultimately, clean-up not only makes disposal simpler but also clean sediment is potentially useful for a variety of beneficial applications.

5. Contaminant assessment and reduction program (CARP)

From a scientific perspective, a strategy for sediment management must be based on a firm understanding of the dynamics of the harbor system. Development of sediment and contaminant mass balances, quantification of contaminant concentrations in water, sediment and biota, identification of contaminant loads, and conceptual modeling efforts are necessary parts of a comprehensive program to develop a better understanding of fate and transport of pollutants into the estuary. After validation, the models may enable assessment of various load reduction scenarios. These source control and clean-up strategies can then be prioritized and implemented in order to meet the contaminant reduction goals set by the Corps of Engineers in their dredged material management report [12,25].

The comprehensive conservation and management plan (CCMP) for the New York/New Jersey [12] describes a strategy for sediment contaminant reduction. This strategy, designated as the contamination assessment and reduction project (CARP), has as its objective the reduction of contamination in harbor sediments to levels that will allow dredged material to meet state and federal criteria for unrestricted disposal or beneficial use. The primary question to be addressed by CARP is, “What sources of contaminants need to be reduced or eliminated to render future dredged material clean, and how long will it take?" The program includes various activities, such as assessing the interactions of contaminants with water, sediment and biota and evaluating these interactions in response to changing contaminant inputs throughout the harbor and estuary. The complete study will provide the technical basis, through comprehensive data collection and modeling activities, for an estuary-wide contaminant reduction strategy. It is expected that CARP will also provide technical information to support waste allocations and other regulatory actions that will be required to bring harbor waters into water quality compliance.

The collection of ambient water, sediment and biota data, along with monitoring of contaminants from specific sources in order to quantify loads, is being conducted by the states of New York and New Jersey. Field and laboratory programs are already underway to collect critical data and will continue for the next several years. The New York State Department of Environmental Conservation (DEC) and the New Jersey Department of Environmental Protection (DEP) supervise the data collection efforts. Fieldwork is being performed by DEC and DEP staff with assistance from the US Geological Survey and various academic institutions. The laboratory work is being conducted by several analytical facilities under contract to DEC and DEP. The field and laboratory programs seek to characterize contaminants in water, sediment, and biota, and to identify and quantify the contaminants entering the estuary. In addition, CARP is conducting an extensive quality assurance/quality control (QA/QC) program. The data will be fed into a numerical model for predictive applications. The Hudson River Foundation is responsible for managing the QA/QC program for the data collection efforts and will supervise the development of models to link sediment contamination with the sources of contaminants. This investment is thought to be prudent because a modest level of contaminant reduction into the New York/New Jersey Harbor could result in savings of millions of dollars in disposal costs.

6. Industrial ecology approach

In 1980s, the emphasis in the regulatory world shifted from end-of-the-pipe approaches towards waste reduction and pollution prevention at the source. Nevertheless, the idea that economic activities must internalize their environmental consequences and costs was a new one for the business community. Design and decision processes often acknowledged the environment only as an additional cost burden imposed from the "outside". However, the 1990s brought forth a global call for "sustainability" in economic development. Since that time, there have been numerous activities to assist planners and engineers to reconcile future economic development with its environmental influences. One of these approaches is the emerging methodology of industrial ecology [29].

The conceptual basis of industrial ecology focuses on a systems approach to measuring interactions between the economic world and the physical environment. Manufacturing operations, product consumption and waste utilization are reconfigured to optimize their total material and energy cycles [30]. Materials and energy are tracked quantitatively in time and space in order to measure changes. In essence, industrial operations are starting to mimic natural ecosystems where every output becomes the input for some other use [31]. In industrial ecology, there are no wastes. Allen and Behmanesh [32] advocate that post-consumer waste, industrial scrap, unwanted by-products from manufacturing operations and construction residues should not be considered as wastes to be disposed but as resources to be recycled and utilized. In a closed system, as is the planet Earth, this approach is essential if humans desire not to ultimately be poisoned. Unfortunately, many areas in the world have already been contaminated, such as the Hudson–Raritan watershed.

Industrial ecology concepts are now being applied to help ameliorate the situation. The New York Academy of Sciences [30] held a workshop to assess the potential applications of industrial ecology to the New York Harbor. The findings indicated that priority should be given to toxicants in the harbor's sediments. By tracing mass balances and material flows in terms of production and consumption behavior, the workshop participants suggested that industrial ecology could illuminate the extent to which economic activities are contributing to continued contamination. The ultimate recommendation from the Academy's workshop was to develop an industrial ecology analysis of five critical contaminants with respect to their flow into the harbor [30]. In 1998, the Academy embarked on a 3-year effort to develop pollution prevention strategies for several toxicants of concern affecting the harbor, using a broad-based consortium of representatives from industry, environmental groups, government, universities and community representatives [33]. The first two chemicals being analyzed using industrial ecology tools are mercury and cadmium. The consortium will select additional chemicals in the future. The analyses are being used to frame long-term, science-based solutions, and participants are designing outreach programs to communicate these solutions to the general public in order to gain a strong commitment for their implementation.

7. Linking research activities

The CARP and the industrial ecology studies can mutually benefit from the linking of their respective research activities. The CARP is focusing on the aquatic environment and the Academy is assessing the loadings that may enter the system from land-based sources. Achieving their individual objectives will be helped by quantitative linkage of their findings. For example, the CARP data will be analyzed to suggest spatial and temporal distributions of contaminant fluxes during normal and peak events. The industrial ecology study may identify point and non-point sources that contribute to sediment contamination and, also, lead the way to non-polluting alternative processes and products. Development of a materials balance for specific contaminants, using both field and inventory data, will be very useful in quantifying the transport and fate specific inorganic and organic contaminants in the basin. Linking a specific contaminant concentration in the harbor to a specific upstream source is the first step in the trackdown and reduction program. Pollution prevention measures could then be applied to the source and clean-up techniques to the contaminant sink. Graphical presentation of the data using geographic information systems (GIS) technology will be valuable to research scientists, harbor managers, policy makers and the general public for analyzing and explaining the data and the findings of these investigations.

There are other types of monitoring activities that can improve sediment quality. Examples include: (1) targeted trackdown and clean-up of contaminant sources within sewage collection systems and in small tributaries; and (2) development of a long-term monitoring and management system to gauge and react to the progress of contaminant reduction plans. Similar long-term monitoring and management programs are currently underway at several other estuaries, including Puget Sound, San Francisco Bay and Chesapeake Bay.

8. Conclusions

There is little doubt that the mass flows and sediment concentrations of anthropogenic pollutants in the New York/New Jersey Harbor are decreasing appreciably with time and in some cases, like mercury, are coming close to the pre-anthropogenic levels. At the same time, high concentrations persist in certain areas because many contaminant sources, such as combined sewer overflows and non-point sources discharges, remain uncontrolled. The contaminant burden makes it difficult and expensive to disposal of the port's dredged sediments, but the sediments must continue to be dredged if the port is to remain a major transportation hub for the nation.

The plight of the Port of New York and New Jersey is an example of how important it is to have sound science and a management framework to guide decision-makers actions. A significant contribution to improved dredged material management in the port would be the development of a basin-wide, watershed-based sediment management strategy. The initial steps are already underway, but it is necessary to link their findings and interpret the results. Combining the findings of CARP's field sampling and trackdown activities with the findings of the New York Academy of Sciences' industrial ecology assessment of contaminant sources and sinks will provide a powerful tool to be used for understanding what needs to be done and for implementing remedial actions. The data analysis and the integration of multiple sets of physical and biological data can be done by means of computerized numerical models and the results presented to policy makers and the general public by means of geographic information systems technology. This basin-wide assessment should be tightly coupled with existing regulatory and management programs in the two states, in order to target and implement contaminant reduction activities as quickly as possible. In the long-term, pollution prevention activities are the only way to continue reducing the contaminant loading into the harbor and to allow its biological resources to recover and flourish.

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